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Boundedly rational consumers, energy and investment literacy, and the display of information on household appliances*

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Abstract

It is an ongoing debate how to increase the adoption of energy-efficient light bulbs and household appliances in the presence of the so-called 'energy efficiency gap'. One measure to support consumers' decision-making towards the purchase of more efficient appliances is the display of energy-related information in the form of energy-efficiency labels on electric consumer products. Another measure is to educate the consumers in order to increase their level of energy and investment literacy. Thus, two questions arise when it comes to the display of energy-related information on appliances: (1) What kind of information should be displayed to enable consumers to make rational and efficient choices? (2) What abilities and prior knowledge do consumers need to have to be able to process this information? In this paper, using a series of recursive bivariate probit models and three samples of 583, 877 and $1,375$ Swiss households from three major Swiss urban areas, we show how displaying information on the future energy consumption of electrical appliances in monetary terms, i.e. as an estimate of yearly energy cost (CHF) rather than in physical units (kWh), increases the probability that an individual performs an investment analysis and hence chooses the most (cost-)efficient appliance. In addition, our econometric results suggest that individuals with a higher level of energy and, in particular, investment literacy are more likely to perform an optimization rather than relying on a decision-making heuristic and are more likely to identify the most (cost-)efficient appliance.

Keywords: energy-efficiency, bounded rationality, energy-using durables, information, energy label, energy literacy, choice experiment

JEL Classification Codes: D12, D80, Q41, Q48

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1 Introduction

In 2014, the residential sector consumed nearly 30% of the total final energy consumption in Switzerland and about 58% of the energy end-use consumption of households was based on fossil fuels (BFE 2015). Improving the energy efficiency in the residential sector is therefore one of the strategies to reduce total fossil energy consumption and related CO_2-emissions in Switzerland. While a major effort needs to be done to enhance energy efficiency of buildings to reduce the consumption of heating fuels, there is also a potential for enhanced energy efficiency in the electricity consumption of Swiss households. One important strategy to reduce electricity consumption of Swiss households is to foster the adoption of energy-efficient lighting and household appliances. A low adoption of energy-efficient technologies is often related to the 'energy-efficiency gap' (Sanstad and Howarth 1994a, Howarth and Sanstad 1995, Allcott and Greenstone 2012), i.e. the frequent observation that individual decision-makers do not choose the most energy-efficient appliance, even if this appliance is also the most cost-efficient choice from the individual's point of view (minimizing lifetime operating costs).[1] The list of potential underlying reasons for the 'energy-efficiency gap' is long and includes a myriad of market and behavioral failures (Sanstad and Howarth 1994b, Broberg and Kazukauskas 2015). A large body of literature studies, for example, (implicit) subjective discount rates and their role for the persistence of the energy efficiency gap (Hausman 1979, Train 1985, Coller and Williams 1999, Harrison et al. 2002, Epper et al. 2011, Bruderer Enzler et al. 2014, Min et al. 2014). In this paper, we abstract away from subjective discounting and other market and behavioral failures to focus on those market and behavioral failures that are related to the provision and processing of energy-related information.

For instance, in order to choose between two similar electrical appliances that differ in price and electricity consumption, a consumer should perform an investment analysis, i.e. solve an optimization problem based on a variety of information that needs to be gathered before or during the purchase: it requires to compare the lifetime cost of different appliances and to choose the appliance that minimizes the sum of the purchase price and the present value of future energy costs (Sanstad and Howarth 1994a,b). This optimization is based on the prices of the appliances to choose from, the electricity consumption of the respective products, the expected intensity and/or frequency of use, the expected lifetime of the appliance as well as current and future electricity prices. If markets provide

[1] It is important to note that throughout this paper, we define cost-efficiency from the (private) point of view of the individual and not from a societal point of view in which we would also have to account for the avoidance of external cost in the production of electricity.

too little or inadequate information about these parameters, or if this information is not salient enough to the consumer, this constitutes a barrier to solving the optimization problem (Sanstad and Howarth 1994a).

In fact, in many purchase situations, the information about the energy-efficiency of an appliance and thus about the future energy costs is less salient than the purchase price. In these cases, it requires an extra effort on the part of the consumer to search for this information. One important attempt to overcome this market failure is the disclosure of energy-related information in the form of energy-efficiency labels on light bulbs and appliances (Sanstad and Howarth 1994b, Broberg and Kazukauskas 2015), as implemented in many countries, including Switzerland. However, even if information on the energy consumption of the appliance is provided, the optimization regarding the lifetime cost of an appliance depends on additional information, such as the current and future electricity price, the frequency or intensity of use of the respective appliance and its expected lifetime.

To carry out the optimization, the consumer needs to gather the required information and then, in a next step, process this information correctly for a minimization of lifetime cost. This creates both 'information cost' and 'optimization cost' (Conlisk 1988) on the part of the consumer, given that the consumer needs to deliberate upon the options to choose from and that this process of deliberation requires cognitive skills and effort. Acknowledging the presence of 'deliberation cost' (Pingle 2015) is equivalent to acknowledging that individuals are 'boundedly rational' (Simon 1959, Sanstad and Howarth 1994a), which means that they are not always able to acquire and process all the necessary information to trade-off all the alternatives in real decision making situations. This is because information acquisition is costly and the processing of information is cognitively burdensome. As a consequence of being boundedly rational, individuals tend to have problems in solving the optimization problem when making an investment decision. Decision-makers therefore often rely on simple rules of thumb or decision heuristics instead of maximizing their utility (Wilson and Dowlatabadi 2007, Frederiks et al. 2015), which potentially widens the energy efficiency gap.[2]

Against the background of the described information-related market and behavioral failures, the research presented in this paper deals with the question how information on the future energy consumption of an appliance should be displayed on products in order to enable consumers to identify the appliance (or light bulb) that minimizes lifetime cost. Furthermore, we investigate whether and

[2]Alternatively, individuals may be inattentive to energy information on rational grounds, assuming that taking future energy cost into account would be a minor factor in their calculation anyway (Sallee 2014). This aspect, however, is not in the focus of our discussion in this paper.

to what extent cognitive abilities and energy literacy support consumers in solving the optimization problem and hence to choose the most cost-efficient appliance. We hereby assume that consumers might follow two different types of decision-making strategies: One of these strategies, that is in line with the neoclassical concept of a fully rational and informed consumer, is to solve the optimization problem, i.e. to choose the appliance that minimizes the lifetime cost for the provision of a specific energy service. The other type of decision-making strategy, which is in line with the concept of bounded rationality, is heuristic decision-making, i.e. choosing an appliance according to a specific and salient characteristic of the appliance, e.g., a low purchase price, a high energy-efficiency rating on the energy label or a lower physical energy consumption.

The choice of the decision-making strategy is determined, on the one hand, by the information that is readily available in the purchase situation, e.g. in the form of information display on the products. On the other hand, it is determined by several socioeconomic factors as well as by factors related to level of energy and financial literacy. The latter influence the individual-specific deliberation cost, i.e. the cost of making the calculation to identify the appliance with the minimum lifetime cost. We thus assume, that the deliberation cost are a function of energy and investment literacy, with energy literacy being defined as the individual's prior energy-related knowledge, such as knowledge about energy prices and energy consumption of different appliances, and investment literacy being defined as the individual's ability to perform an investment analysis.

With respect to the question on how to display information to enable consumers to choose more energy-efficient appliances, some existing research evaluates the role of declaring future energy consumption of an appliance either in the form of monetary information or physical information (McNeill and Wilkie 1979, Anderson and Claxton 1982, Heinzle 2012, Newell and Siikamäki 2014, Min et al. 2014), assuming that monetary information can be processed more easily by the consumer. The results of these studies are inconclusive as they find different effects of displaying energy consumption information in physical or monetary units on appliance choice. While McNeill and Wilkie (1979) and Anderson and Claxton (1982) do not find any effects, the results in Heinzle (2012), Newell and Siikamäki (2014) and Min et al. (2014) suggest that displaying monetary information supports the choice of more efficient appliances. Yet, while the results presented in Heinzle (2012) for TV sets suggest that only the display of lifetime operating cost is supportive to the choice of efficient appliances, Newell and Siikamäki (2014) and Min et al. (2014) find that also the display of annual operating cost positively impacts on consumers choice of efficient water heaters and light bulbs, respectively. In addition, in these papers, the consumers' knowledge and cognitive abilities, i.e. their energy and investment literacy, are not considered. Therefore, this paper contributes to the existing literature along three dimensions: First, further empirical evidence is provided on the role of displaying monetary information on the future energy consumption of an appliance for choice of electrical appliances. Second, according to our best knowledge, this is one of the first studies which analyzes the impact of the level of energy literacy on the choice of electrical appliances and the impact of energy literacy, investment literacy and monetary information on the choice of the decision making strategy (optimization vs. heuristic decision making). Lastly, we also analyze the impact of the decision making strategy on the choice of the appliance.

In order to examine the role of information display, energy and investment literacy on the choice of electrical appliances of boundedly rational consumers, we have organized a household survey and conducted two online randomized controlled choice experiments. The information collected from the survey have been utilized to estimate a series of (recursive) bivariate probit models based on data from three samples of 583, 877 and $1,375$ Swiss households from three major Swiss urban areas. In the empirical part of the paper, we compare individual appliance choice given either monetary or physical information about future energy consumption while accounting for the respondents' energy and investment literacy, their attitudes towards energy conservation, as well as their sociodemographics. We find that displaying consumption information in monetary terms rather than in physical units enhances the individuals' ability to choose the most efficient appliance. Furthermore, individuals with a higher level of energy and investment literacy are more likely to choose the most efficient appliance. Moreover, the monetary information treatment and the energy and investment literacy positively influence the probability to perform an investment analysis which in turn increases the probability to choose the most (cost-)efficient appliance. This supports the view that both displaying of monetary information on future energy consumption as well as consumers' prior knowledge and cognitive abilities are decisive factors for reducing the energy-efficiency gap. Investing in consumer education to increase their energy and investment literacy could thus be an important element in a set of policy measures to enhance residential energy efficiency.

2 Literature review and hypotheses

In the following, we review the literature that investigates into the effects of energy information display on the adoption of efficient technologies as well as the literature on the role of energy and investment literacy for the choice of efficient appliances.

2.1 The role of energy information display for the choice of efficient appliances

Early studies investigating the role of energy information display for the choice of efficient appliances are McNeill and Wilkie (1979) and Anderson and Claxton (1982). In McNeill and Wilkie (1979), a hypothetical choice experiment with refrigerators is conducted among 155 female respondents from Gainesville, Florida. In the different treatment conditions, information on energy consumption of the refrigerator is either present or absent. If present, it is displayed either in terms of dollars or kilowatt hours, and either in comparison to other similar products or only in absolute terms. No effect of energy information display on choices was found. Also, no effect of displaying monetary vs. physical information on energy consumption on respondents ranking of different refrigerator models with respect to their energy performance could be identified.

Anderson and Claxton (1982) present results from a field experiment in a national department store chain in Canada, in which refrigerators were either presented with kilowatt hour labels (monthly energy consumption in kWh) or dollar cost labels (yearly energy cost). While they report that the presence of energy information had a significant impact on appliance choice only for small refrigerators, no effect of information display either in physical or monetary terms could be found.

In a more recent study, Heinzle (2012) examines the impact that different ways of disclosing energy-related information have on the choice of TVs in online experiments in Germany. The effects of three different disclosure formats of energy labels on appliance choice are compared: operating costs in terms of physical units (kWh), annual energy operating cost in monetary terms and lifetime energy operating cost in monetary terms. Under different treatment conditions, respondents were first asked to estimate the potential savings per year when comparing different TV sets. In addition, a hypothetical choice experiment was conducted in which respondents had to choose between different TV sets. Heinzle (2012) shows that individuals tend to overestimate potential cost savings between two TV sets if provided with information on energy consumption in physical units. Furthermore, a significant influence of the disclosure format on individual's WTP for more efficient TV sets is identified: disclosing energy consumption in monetary terms increased respondents willingness to pay (WTP) for energy efficient TV sets only when lifetime energy cost but not when annual operation cost were displayed. The display of annual energy operating cost in monetary terms even reduced WTP compared to the display in physical units. Related results are reported in Deutsch (2010): based on a randomized field experiment on a commercially operating price comparison website it is shown that disclosing the life-cycle cost of an appliance instead of the purchase price induces consumers to purchase cooling appliances that are on average 2.5% more efficient than in the absence of life-cycle cost disclosure.

Also Newell and Siikamäki (2014) test the effects of different forms of energy efficiency labeling. Among other features, they evaluate the impact of a label including the estimated yearly operating cost versus the impact of a label including physical information on energy use. In a choice experiment among $1,214$ US home owners, they find that providing information on estimated yearly operating cost is more effective in enhancing willingness to pay for more efficient water heaters than providing information about energy use in physical units. These findings are partly in line with the findings in Heinzle (2012), except that in the study of Newell and Siikamäki (2014) the display of annual operating cost (as opposed to lifetime operating cost) had a positive influence on the choice of more efficient appliances. For light bulbs, Min et al. (2014) test the influence of energy labeling on implicit discount rates in an incentivized choice experiment among 168 US residents and also conclude that the provision of information on annual operating costs of the bulbs increases consumers' WTP for more efficient bulbs.

Apart from studies that investigate the impact of the display of energy consumption either in physical or monetary units, there are some studies that also consider the role of energy-efficiency rating scales on the choice of appliances. The results of these studies suggest that the information on energy use provided on energy labels tends to be disregarded in the presence of a rating scale. For example, Waechter et al. (2015) investigate consumers' attendance to the EU energy label by using eye-tracking in a hypothetical experiment on the choice of TVs and freezers in Switzerland. They describe a phenomenon they refer to as 'energy-efficiency fallacy' which goes back to the observation that energy-efficiency information in the form of an efficiency rating may mislead consumers in their evaluation of the energy consumption of a product. Their results suggest that the presence of an energy label with a rating scale makes consumers focus more strongly on the energy efficiency information rather on the annual consumption (in physical units) of an appliance in absolute terms.

Also Hille et al. (2015) find that the presence of an energy efficiency ranking score on the label makes consumers focus predominantly on the energy efficiency rating rather than actual energy consumption. In a study on absolute vs. relative labeling of cars in Germany, i.e. the energy efficiency rating of cars either in absolute terms (compared to cars from all available categories) or in relative terms (compared to cars from the same category) they find that consumers evaluate the environmental performance of an efficient car less favorably when the energy label rates it compared to other cars in the same category (relative labeling) as compared to all available car types (absolute labeling). On the opposite, a highly gasoline-consuming car is rated more favorably when compared to the other cars in the same category as compared to the entire range of available car models. A relative labeling approach thus potentially makes consumers choose cars with higher gasoline consumption if consumers blindly follow the rating score and disregard any additional information on absolute energy consumption.

Both the results presented in Waechter et al. (2015) and Hille et al. (2015) indicate that the display of an energy-efficiency rating scale on electric appliances may divert attention from the information on actual energy consumption of the products, suggesting that the EU energy label in its current form is used as a decision-making heuristic by many consumers, rather than supporting a rational and informed decision making.[3]

2.2 The role of energy literacy and education for the choice of efficient appliances

Another potentially important prerequisite for rational decision-making in the domain of energy-efficient appliances is energy literacy, which can be defined as an individual's ability to make informed and deliberate choices in the domain of household energy consumption. In the literature, energy literacy is defined as an individual's cognitive, affective and behavioral abilities with respect to energy-related choices and energy conservation behavior (DeWaters and Powers 2011). According to DeWaters and Powers (2011), energy literacy thus comprises of *(1)* knowledge about energy production and consumption as well as its impact on the environment and society, *(2)* attitudes and values towards energy conservation as well as *(3)* corresponding behavior. In this paper, we use a narrower definition of energy literacy that mainly reflects the individual's knowledge about energy

[3] Of course, if the energy rating score is negatively correlated with the lifetime cost of the appliance, there may still be a chance that consumers who consider the rating scale on the label make, consciously or unconsciously, a rational decision from the societal point of view, i.e. when also the avoided negative externalities from electricity production are taken into account.

prices and the energy consumption of different household appliances. This is because our main goal is to examine what knowledge and cognitive abilities consumers need to have in order to identify cost-efficient appliances.

With respect to investments in energy-efficient appliances, an additional component gets relevant: investment literacy, i.e the individuals' ability to perform an investment analysis and hence to correctly evaluate different investment alternatives, for example when choosing appliances, heating systems or when deciding about energy-saving renovations. Regarding this ability, the literature on financial literacy is informative. Lusardi and Mitchell (2009) show, for example, that more educated people are more likely to correctly answer a question on compound interest and that this indicator of financial literacy has a relevant influence on economic decisions in several domains: inter alia, individuals who know about interest compounding are 15 percentage points more likely to be retirement planners (Lusardi and Mitchell 2007). In a study on financial literacy in Switzerland, Brown and Graf (2013) find that respondents scoring high on financial literacy are more likely to have an investment related custody account and to make voluntary retirement savings.

One of the first studies that investigates the effect of energy and investment literacy on electricity consumption in a large sample is the study from Brounen et al. (2013). They examine the effect of energy and investment literacy on household conservation behavior and energy consumption in an online survey in the Netherlands. Their indicators for energy and investment literacy are three items capturing the households' awareness of the amount of their monthly gas/electricity bill, the respondents' choice in a decision between two alternative heating systems with different levels of energy efficiency, and the answer to the question whether the household uses green electricity. They find that older and male respondents are more likely to know about their gas bill and that more educated respondents are more likely to make a rational investment decision in the heating system example. However, Brounen et al. (2013) do not find that energy literacy has an impact on energy conservation behavior among the sampled households in terms of thermostat settings, and also not on the overall electricity and gas consumption of the household.

In addition, there seems to be a role for education more generally when it comes to energy-related decision-making. While an individual's level of education does not necessarily need to correlate with energy literacy and energy-related investment literacy, some studies find a positive correlation of these two constructs with an individual's general level of education. For example, Mills and Schleich (2010) find that education, among other socio-economic characteristics, is positively correlated with knowledge about energy efficiency labels on appliances. In another study, Mills and Schleich (2012) build an energy-related knowledge index and find that the knowledge index increases when the most educated member of the household has an university degree, whereas a high-school degree does not have any effect and vocational training has a negative effect on the knowledge index. Also Nair et al. (2010) report from a Swedish sample that a higher level of education as well as a better knowledge about energy efficiency measures in buildings increases the likelihood that a household invests in building envelope measures.

Apart from the study of Brounen et al. (2013), there is only little research about the role of energy literacy and energy-related investment literacy on investment decisions in the domain of residential energy consumption. In particular, we are not aware of any study that investigates the impact of energy and investment literacy on the choice of household appliances. This paper aims at filling this gap.

2.3 Theoretical considerations and hypotheses

In the following, we provide some theoretical reasoning that can explain the role of energy information display, energy literacy and financial literacy on the choice of appliances.

According to household production theory (Deaton and Muellbauer 1980) households purchase inputs such as energy and capital (i.e. household appliances) and combine them to produce outputs which are the desired energy services such as cooked food, washed clothes or hot water. These energy services appear as arguments in the household's utility function (Muth 1966, Flaig 1990). The utility function of a household is based on the consumption of both energy services and all other goods and is maximized under the budget constraint. A high level of expenditure for energy services will reduce the options to consume all other goods.

Therefore, when facing the choice of light bulbs or household appliances, consumers are confronted with the optimization problem of choosing the appliance that provides the desired energy service at the minimum lifetime cost. Consumers wish to reduce their overall expenditure for energy services and to maximize their opportunities to consume all other goods, otherwise they experiences a loss in utility. For the minimization of lifetime cost consumers have to consider the purchase price and future operating costs of the appliance, which depend on the energy consumption of the appliance (in Watts), the lifetime of the appliance, the frequency and intensity of use of the appliance during its lifetime as well as on current and future electricity prices.[4]

Lifetime cost and intensity of use cannot be predicted with certainty in the moment an appliance is purchased, so the individual needs to form expectations regarding lifetime cost and intensity of use for each appliance within the set of appliances to choose from. The process of forming expectations and comparing the expected lifetime cost of several appliances requires time and other resources that can be considered as 'decision cost' (Pingle 2015).

To study the role of 'decision cost' for the choice of the decision-making strategy and for the choice of an appliance, we provide a simple 2-period-model of expectation formation that explicitly takes into account the decision cost. This model is based on the model in Conlisk (1988) and assumes that an individual assesses the expected lifetime cost of an appliance before purchase.[5] Similar as in Conlisk (1988), we assume that the individual faces two potential sources of a loss that he or she wants to minimize: *i)* experiencing a loss in inter-temporal utility by either underestimating the lifetime cost of an appliance in period 1 and thus not allocating enough of the budget in period 2 on the consumption of the energy service, or, by overestimating the lifetime cost of an appliance in period 1 and thereby restricting consumption of other goods in period 1 itself due to the individual's budget constraint, and *ii)* spending too much time and resources on decision making itself.

Suppose that the individual thus faces a loss function which takes the following simple form:

$$(E(L(T)) - L)^2 + \beta CT \tag{1}$$

with $E(L(T))$ representing the estimated lifetime cost of the appliance after having spent T units of time and other resources on deliberation, and L representing the true lifetime cost of the appliance. The decision cost βCT are composed of C denoting the unit cost of performing the calculation task and T denoting the amount of time and other resources devoted to deliberation. The parameter $\beta \in [0, 1]$ captures the individual's capacity for performing the calculation task. The lower β, the lower the individual's effort needed to perform the task, and hence the lower the decision cost.

As both $E(L(T))$ and L contain random elements that cannot be perfectly predicted (e.g., the future

[4] Also the individuals' subjective discount rates will influence the outcome of the optimization. Yet, in the following model, the discount rate is assumed to be a constant factor that is not modeled explicitly. Including discounting in our analysis would not change any of the results.

[5] Note that the theoretical model in Conlisk (1988) concerns a completely different macroeconomic setting wherein a model for a worker's expectation formation of future price level was considered. Here, we have implemented the theoretical model in the framework where we examine an individual's expectation of the lifetime cost of a household appliance which eventually determines whether or not the individual chooses this appliance.

electricity price, frequency and intensity of use of the appliance) and because the individual does not know in advance to which result $E(L(T))$ his or her costly reasoning will lead, the individual will form expectations over both $E(L(T))$ and L and minimize the following objective function to determine the optimal investment in terms of time and other resources, $T^{\star}$:

$$Min! \quad E[(E(L(T)) - L)^2] + \beta CT \tag{2}$$

The lifetime cost of the appliance that was estimated after having invested the optimal amount of units $T^{\star}$ for decision making can thus be expressed as $L(T^{\star})$ and can be considered as a realization of the random expectation variable $E(L(T))$.

Next, we assume that we can define R as the rational expectation of L and that individual j's estimate $E(L(T))$ of R is a weighted combination of two elements: a free estimator f, that is based on a simple rule of thumb and is thus generated without any decision cost, and a costly improvement of f denoted as $r(T)$, that depends on the time spent on deliberation. We further assume that the individual makes his or her decision as if the costly improvement $r(T)$ was as accurate as a sample mean of T independent observations taken from a distribution with mean R and variance σ^2 and as if f was as accurate as a sample mean of S independent observations which represents less number of draws taken from the same distribution with mean R and variance σ^2.

The intuition here is that for an individual who performs a detailed analysis, it would imply drawing a large number of T thoughts from the distribution with mean R and variance σ^2 thereby increasing the probability that he or she arrives close to R which is the rational expectation of L. However, in a heuristic approach (rule of thumb), the judgment can be considered to be based just upon only a very few number of S thoughts, which can a priori be assumed to be objectively biased (note that from the point of view of the individual, the guess itself may be considered unbiased otherwise he or she would make a different guess altogether).

Based on these assumptions and following the reasoning of Conlisk (1988), we can write the estimate of the lifetime cost to be:

$$E(L(T)) = \frac{S\,f + T\,r(T)}{(S+T)} \tag{3}$$

The expected value of this estimate would be R and its variance would be $E[(E(L(T)) - R)^2]$, which corresponds to $\sigma^2/(S+T)$. We can therefore rewrite the objective function defined in equation (2) as follows:

$$Min! \quad \frac{\sigma^2}{(S+T)} + \beta CT \tag{4}$$

Minimizing this objective function, we can derive the optimal investment of time and other resources for decision making:

$$T^{\star} = \frac{1}{\sqrt{\beta C/\sigma^2}} - S \tag{5}$$

It is obvious that the lower bound for the optimal time spent on deliberation $T^{\star}$ is at least 0. This equation gives us some insight into the optimality of different decision-making strategies. Consider the case when an individual has a lower capacity to perform a calculation task (i.e. higher β) and the analysis is costly relative to the size of the problem (large C/σ^2) to the extent that the initial guess is reliable (large S). If these conditions hold with enough force, the corner solution $T^{\star} = 0$ applies and the individual spends no resources on deliberation but only follows the rule of thumb f which in this case is good enough.

Substituting T by $T^{\star}$ in equation (3), we can rewrite the individual's expected lifetime cost of the appliance as:

$$E(L(T^{\star})) = \alpha f + (1-\alpha) r(T^{\star}) \tag{6}$$

with

$$\alpha = \frac{S}{(S+T^{\star})} = S\sqrt{\beta C/\sigma^2} \tag{7}$$

By definition, α has an upper bound of 1 when the corner solution $T^{\star} = 0$ applies, i.e. when individual's rule of thumb choice is good enough. Equation (6) can be seen to cover both the extremes; when $T^{\star}$ goes to infinity, the expected lifetime cost converges to the rational expectation R. On the other hand, when $T^{\star} = 0$, i.e. when $\alpha = 1$, the expected lifetime cost is the free estimator f. Depending upon the different parameters, an individual could be lying anywhere between the range of unboundedly rationality and a rule of thumb approximation (Conlisk 1988).

The estimation of the lifetime cost of the appliance will thus be more closer to the rational expectation R as α gets smaller. From equation (7), α is the lower

- the lower β, i.e. the lower the individual's effort needed to perform the estimation of lifetime cost of the appliance

- the lower C relative to σ^2, i.e. the lower the decision making cost related to the complexity of the problem
- the lower S, i.e. the lower the amount of (costless) best guesses spent on estimating R, i.e. the less reliable the rule of thumb

Any individual having to decide between several appliances on offer, will first assess the lifetime cost of all the appliances separately and then in a second step compare them to identify the one with the minimum lifetime cost. From the above described model, we derive two hypotheses with respect to whether the individual rather deliberates or follows a rule of thumb when comparing the appliances (choice of decision-making strategy). As a natural consequence, but not directly related to the above theoretical model, we can identify two more hypotheses in relation to what determines whether the individual successfully identifies the most cost-efficient appliance (choice of cost-efficient appliance).

First, we expect that individuals with a higher level of energy and investment literacy are more likely to choose an investment analysis as the decision-making strategy as the process of deliberation is less costly to them, i.e. a lower β in the theoretical model (*H1a*). We further assume that disclosing yearly energy consumption in monetary terms (CHF) rather than in physical units (kWh) decreases the value of C and hence increases the probability that the individual carries out an investment analysis rather than following a heuristic decision-making strategy as this lowers the per unit cost of deliberation (*H1b*).

In a second step when an individual compares the lifetime costs of two appliances, we expect that an individual that carries out an investment analysis is more likely to identify the more cost-efficient appliance (*H2a*). In addition, we expect that disclosing yearly energy consumption in monetary terms increases the probability that the individual identifies the more cost-efficient appliance, again, as the display of monetary information lowers the per unit cost of deliberation (*H2b*).

Our hypotheses can be summarized as follows:

- *H1a:* The level of energy and investment literacy has a positive impact on the individuals' ability to follow an optimization strategy rather than a heuristic strategy.
- *H1b:* Displaying information on the yearly energy consumption of an appliance in monetary terms rather than in physical units has a positive impact on the individuals' ability to follow an optimization strategy rather than a heuristic strategy.

- *H2a:* Opting for optimization as the decision-making strategy has a positive impact on the probability to identify the most cost-efficient appliance.

- *H2b:* Displaying information on the yearly energy consumption of an appliance in monetary terms rather than in physical units has a positive impact on the probability to identify the most cost-efficient appliance.

3 Experimental design

In this paper we use an explanatory research approach in order to examine the role of information, energy and financial literacy on the choice of the decision-making strategy for choosing an electrical appliance, as well as on the choice of the appliance itself. For this purpose, we have organized a web-based survey in which two online randomized control experiments were embedded. The information collected from the survey and the experiments are utilized to estimate a series of probit models to test our hypotheses and to identify the most important factors that explain the choice of electrical appliances by Swiss consumers. The survey has been organized in cooperation with three Swiss electricity providers operating in three major urban areas in Switzerland (Lucerne, Bellinzona, Biel/Bienne). The two online experiments were part of the online survey, which was conducted among electricity and gas customers during the year 2015. For this survey, customers of the electricity providers were invited with a letter accompanying one of their electricity (or gas) bills to access an online questionnaire. The invitation letter was sent to a total of 50'000 (Lucerne), 30'000 (Bellinzona) and 38'000 (Biel) customers of which 1'999 (Lucerne), 958 (Bellinzona) and 1'308 (Biel) accessed the survey page (corresponding to response rates of 4% (Lucerne), 3.2% (Bellinzona) and 3.4% (Biel)). After accounting for duplicate entries and missing values, we have valid and complete data for $1,375$ (Lucerne), 583 (Bellinzona) and 877 (Biel) survey respondents that can be used for our analysis.

The three observed samples should represent the Swiss population living in small cities. Unfortunately, the availability of some information about socioeconomic variables at the city level is limited. Therefore, we compare our sample to the average values available for the entire Swiss population. The average values of the three cities deviate from the Swiss population averages in some characteristics (for an overview see Table 1). Across all three samples, we observe that older and male respondents, respondents from couple as compared to single households, as well as more educated respondents are slightly over-represented. The share of respondents who donated money to an environmental organization within the 12 months preceding the survey is largely in line with the share reported for the Swiss population (with a slightly lower share in Bellinzona), which suggests that our sample does not seem heavily biased towards households with pro-environmental attitudes. While lower and middle incomes are well represented, higher incomes seem to be less well represented, but could also make up a high share of the respondents who did not indicate their incomes (up to 20% in Bellinzona).

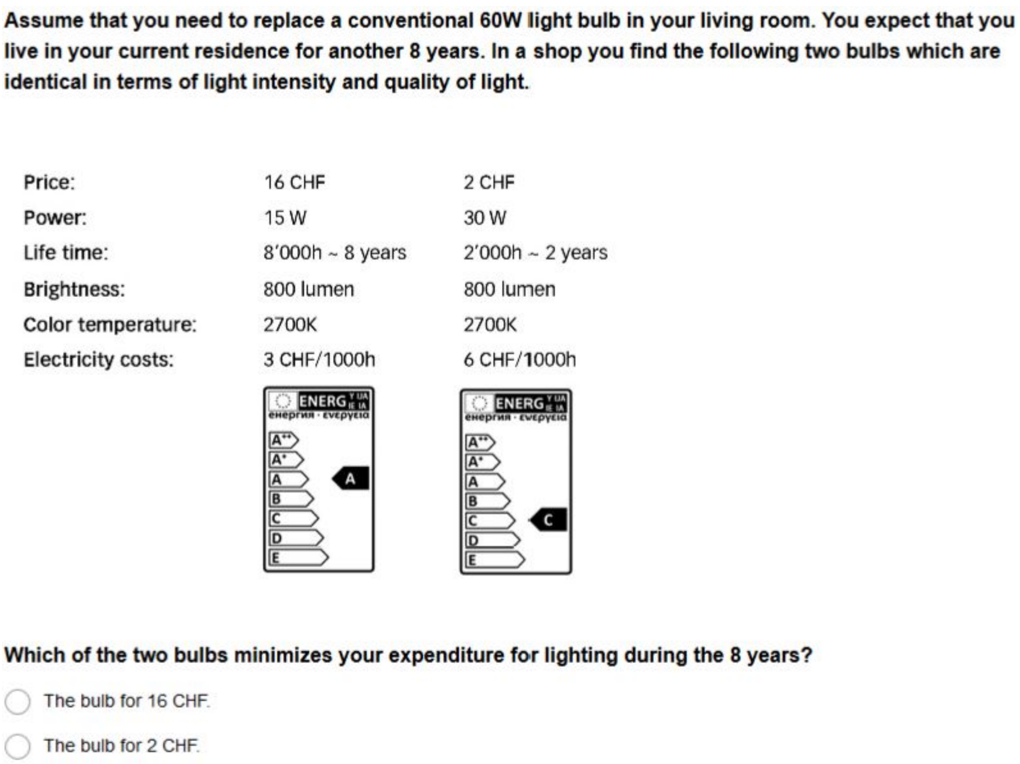
Table 1: Characteristics of respondents in the samples compared to Swiss population averages.

Sample	**Bellinzona** N=583	**Biel/Bienne** N=877	**Lucerne** N=1375	**Swiss pop.***
Female	38.8	44.7	39.9	50.5
Age < 40	27.4	19.3	26.8	46.9
Age 40-59	47.2	38.8	33.1	29.7
Age 60+	25.4	42.0	40.2	23.4
Academic degree**	33.1	36.3	39.7	16.3
1 pers. HH	20.2	29.4	29.8	35.1
2 pers. HH	34.3	44.9	48.0	32.7
3 pers. HH	20.9	11.2	9.6	13.3
4 pers. HH	17.2	9.3	9.0	12.8
5+ pers. HH	7.4	5.2	3.5	6.1
Donations to env. org.	32.8	48.9	42.0	42.0
Gross household income; Swiss average (2013): 10'052 CHF				
up to 6000 CHF	28.3	35.0	27.0	29.3
6001 to 12000 CHF	44.4	40.8	43.6	45.0
more than 1200 CHF	8.1	13.2	15.1	25.7
not indicated	19.2	11.0	14.3	-

*Swiss Statistics (BFS): Swiss population by income (data from 2013), age, household size (data from 2014), education (population 25+ in 2014), gender (data from 2015); GFS Spendenmonitor 2014: share of population donating to environmental organizations (data from 2014).

**Academic degree defined as graduated from a university or university of applied sciences.

One of the two experiments was embedded towards the end of the online surveys. Customers of the utilities in Bellinzona and Lucerne saw *Experiment 1*, customers of the utilities in Biel/Bienne saw *Experiment 2*. Survey respondents who saw *Experiment 1* were asked to imagine a situation in which they had to replace a light bulb in their living room. As a replacement, they had the choice between two bulbs that differed in their purchase price, power, lifetime, electricity cost as well as energy efficiency rating (A versus C rating). This information display corresponds to the current version of the EU energy label for light bulbs (see Figure 1). It is important to note that the two described bulbs only differed in price and energy-related characteristics but not in their color temperature and brightness.



Assume that you need to replace a conventional 60W light bulb in your living room. You expect that you live in your current residence for another 8 years. In a shop you find the following two bulbs which are identical in terms of light intensity and quality of light.

Price:	16 CHF	2 CHF
Power:	15 W	30 W
Life time:	8'000h ~ 8 years	2'000h ~ 2 years
Brightness:	800 lumen	800 lumen
Color temperature:	2700K	2700K
Electricity costs:	3 CHF/1000h	6 CHF/1000h

Which of the two bulbs minimizes your expenditure for lighting during the 8 years?

- The bulb for 16 CHF.
- The bulb for 2 CHF.

Figure 1: The light bulb choice task as presented in Experiment 1 (treatment with display of energy consumption in monetary terms).

Respondents were randomly assigned to four different treatments. In *Treatment 1*, the information on yearly energy consumption of the two bulbs was displayed in terms of physical consumption (kWh) per 1000 hours, as it is displayed in the current version of the EU energy label. In *Treatment 2*, energy consumption was again displayed in terms of physical consumption (kWh), yet 'per year' instead of 'per 1000 hours'. In *Treatments 3 and 4* the information on electricity consumption was displayed in monetary terms, i.e. in the form of an estimate of the yearly energy cost (in CHF), in one treatment 'per 1000 hours' (see Figure 1), in the other 'per year'. Additionally, we controlled for order effects by randomly changing the order of presentation of the two light bulbs in all four treatments.

Respondents were asked which of the two light bulbs would minimize their expenditure for lighting during 8 years of planned usage. Thus, the question was not about the respondent's subjective preference for either the one or the other bulb, but about which of the two bulbs entails less lifetime costs, from an objective point of view. In principle, the result of the comparison of lifetime cost will also be driven by the individual's subjective discount rate. Assuming that the average participant of our study is not familiar with the concept of discounting and would need a calculator to incorporate discounting in the analysis, we refrained from providing respondents with a 'reference discount rate' that they should use. Instead we assumed that consumers, in case they opted for an investment analysis, would consider the undiscounted future operating cost to evaluate the lifetime cost of the two bulbs. Probably because of a similar reasoning also Allcott and Taubinsky (2015) present undiscounted operating cost in an online experiment on consumers' choices of light bulbs.

The respondents who saw *Experiment 2* were asked to imagine a situation in which they need to replace their refrigerator. They were given a choice between two refrigerators that differed only in terms of their purchase price and their energy consumption. The remaining characteristics of the two refrigerators were identical. The information was presented in the same way as it is presented in the current version of the EU energy label for refrigerators (see Figure 2).

The participants were randomly assigned to one of two different treatments. In *Treatment 1*, the information on yearly energy consumption of the two appliances was displayed in terms of physical consumption (kWh), as it is displayed in the current version of the EU energy label (see Figure 2). In *Treatment 2*, the information on electricity consumption was displayed in monetary terms, i.e. in the form of an estimate of the yearly energy cost. Again, we controlled for order effects by randomly changing the order of the two refrigerators in both treatments.

Respondents were asked which of the two refrigerators would minimize their expenditure on the cooling of food and beverages during 10 years of planned usage. Again, the question was not about the respondent's subjective preference for either the one or the other refrigerator, but about which of the two appliances creates less lifetime costs.

In both experiments, also the order of the answer options was randomized in order to control for order effects in the presentation of the answer options. As a general rule, any given answer options in the survey questionnaire were presented in a random order to avoid order bias.

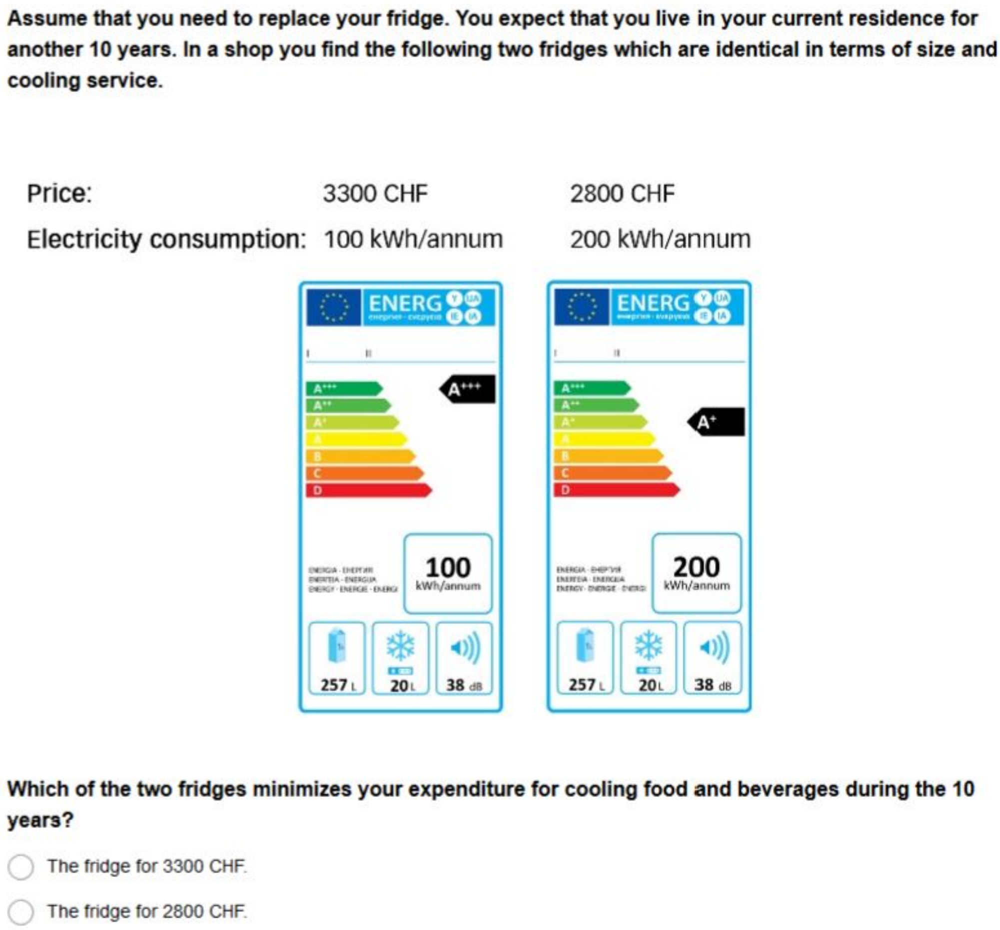


Figure 2: The refrigerator choice task as presented in Experiment 2 (treatment with display of energy consumption in physical units).

While the general setup was very similar in both experiments, it has to be highlighted that they also differed in a decisive way: While in *Experiment 1* the more energy-efficient bulb was also the one that minimizes lifetime cost, *Experiment 2* was designed in a way that the refrigerator with the lower energy consumption, i.e. the more energy-efficient appliance, was not the appliance that minimized lifetime cost. This seems counter-intuitive, as in such a case an 'energy-efficiency gap' does not exist. It is perfectly rational for the consumer to choose the less efficient appliance, at least from a private perspective, as this minimizes lifetime cost. The reason why this specific setting was chosen was to identify those individuals who performed an investment analysis and to distinguish them from the respondents who followed a heuristic decision-making strategy. If the more expensive (and more energy-efficient) appliance would have had the lowest lifetime cost, individuals following a decision heuristic (such as choosing based on the energy-efficiency rating provided on the energy label) would have ended up making the same choice as the ones who performed an investment analysis. This would not allow to discriminate between the two groups of decision-makers.

In a debriefing question after the choice task, which was the same in both experiments, respondents were asked about the decision-making strategy they had adopted when making their choice. Five different choice strategies were offered: one of them being performing an investment analysis (comparison of lifetime cost) and the other four being rather heuristic decision-making strategies such as comparing the purchasing prices of the two products, comparing the yearly electricity consumption, comparing the energy-efficiency ratings on the labels or making a rather random choice. Answer options were again randomized to control for order effects. The introduction of this debriefing question gives us the possibility to econometrically analyze the factors that influence the choice to perform an investment analysis, and, therefore, to adopt a rational decision strategy.

In *Experiment 1*, about 28.3% of the respondents claimed to have compared the electricity consumption of the two light bulbs. About 23.2% mentioned that they made an investment calculation before making the choice. Another 24.7% of the respondents reported to have compared the energy-efficiency ratings on the label and 13.2% said they made their choice based on the lifetime of the two bulbs. 2.9% answered that they had compared the purchase prices of the two bulbs and another 7.7% of the respondents either mention other reasons for their choice or report that they made a rather random choice. In *Experiment 2*, most of the respondents self-reported that they compared the energy-efficiency ratings on the energy labels (45.7% of respondents who answered the debriefing questions). 28.0% of the respondents claimed to have compared the electricity consumption of the two refrigerators, and 17.7% claimed that they made an investment calculation to evaluate the two appliances. Only 2.0% of respondents reported to have compared the purchasing prices, 3.0% indicated that they made a rather random choice and 3.6% stated that they had other reasons for their decision.

In addition to the choice task and the debriefing question, the questionnaire included several other questions related to the household's energy consumption as well as questions on sociodemographics of the respondent and other household members. For this analysis, we included information on respondents' age, gender and level of education, their attitudes towards energy conservation as well as their energy and investment literacy. Attitudes towards energy conservation were captured by two items asking for agreement or disagreement to a statement on a 5-point Likert scale. The two statements were "I feel morally obliged to reduce my energy consumption." and "I am willing to make compromises in my current lifestyle for the benefit of the environment.". Energy literacy was measured by an index that accounts for several dimensions of energy literacy: knowledge of the average price of a kilowatt hour of electricity in Switzerland, knowledge of the usage cost of different household appliances as well as knowledge of the electricity consumption of various household appliances. Investment literacy was measured by an indicator variable that takes the value one if the respondent correctly solved a compound interest rate calculation.[6] Compound interest rate calculations are usually used to assess an individual's financial literacy (Lusardi and Mitchell 2007, 2009, Brown and Graf 2013). Finally, also the fact whether the respondent was owner or renter of his residence was accounted for. An overview of the summary statistics for the variables used in our econometric models for *Experiment 1* and *Experiment 2* is presented respectively in Table 5 and Table 6 in the Appendix.

4 Empirical Model

As discussed previously, the data collected from the survey and from the two experiments allows us to analyze the impact of the display of monetary information about future energy consumption as well as the level of energy and investment literacy on the choice between two light bulbs and two refrigerators. Further, the debriefing question about the decision making strategy gives us the possibility to analyze the factors that influence the choice to perform an investment analysis. Therefore, from the econometric point of view, we are interested in explaining the impact of information, energy and investment literacy and other socioeconomic factors on two binary outcome variables. In one case, the dependent variable takes the value 1 if someone chose the most cost-efficient appliance and 0 otherwise. In the second case when analyzing the decision strategy, the outcome variable takes the value 1 if someone chose to perform an investment calculation and 0 otherwise. From a methodological point of view, such binary outcome variables are the simplest case of a discrete choice situation and can for example be analyzed using a probit model (Greene 2003).

In a probit framework, the expression for the probability of choosing the most (cost-)efficient appliance can be written as:

$$Pr(y = 1|x) = \Phi(\boldsymbol{\beta}'\mathbf{x}) \tag{8}$$

Pr is the probability that the respondent chose the most (cost-)efficient appliance, $\boldsymbol{\beta}$ is a vector of coefficients, and $\mathbf{x}$ represents a set of regressors such as socioeconomic characteristics, a dummy

[6] We asked respondents to imagine that they have 200 CHF in a savings account which earns 10% interest per year. We asked them how much they would have in the account at the end of 2 years, and, again, respondents could choose from pre-defined answer options.

variable indicating whether or not future energy consumption was displayed in monetary terms to the consumer as well as the level of energy and investment literacy and the chosen decision strategy. This model estimates the probability that a (cost-)efficient appliance is chosen instead of a less (cost-)efficient appliance given a set of explanatory variables. Further, this simple probit model can also be used to estimate the probability that an optimization strategy is chosen instead of a more heuristic approach, given a set of explanatory variables. The probit models are usually estimated using maximum likelihood based approach.[7]

The separate estimation of two single equation probit models described above is based on the assumption that the two outcome variables can be independently determined. This may or may not hold true in reality. Although in our context, in which an individual opts for a decision-making strategy and chooses a cost-efficient appliance, it can be safely assumed that the two outcome variables should be determined jointly rather than individually. In this case, we need an econometric model that jointly explains two binary variables: performing an investment calculation and identifying the cost efficient appliance. From an econometric point of view a bivariate probit model could be applied for a simultaneous estimation of the two binary outcome variables.

Furthermore, even more precisely, the choice of the most cost-efficient appliances could be modeled as a **two stage decision process**, explaining first the choice to adopt a decision strategy based on an investment calculation, and then the choice of the cost efficient appliance. In this case, an appropriate econometric model for this sequential choice is the recursive bivariate probit as it accounts for the likely endogeneity of the investment calculation variable in the equation related to the choice of the cost efficient appliance. Note that our preferred model is the recursive bivariate probit because of the reasons laid out here. Most of the following discussions and results refer to this model. Nevertheless, in this paper we still decided to estimate two separate probit models and a bivariate probit model for each of the two experiments for comparison purposes.

The recursive bivariate probit approach, also denoted as *a recursive model of simultaneous equations* by Greene (2003), was proposed by Burnett (1997) who analyzed the presence of a gender economics course in the curriculum of a liberal arts college. In a follow-up work, Greene (1998) provided an alternative theoretical specification and a maximum likelihood based estimation approach for an

[7] The focus in this paper is on the effect of performing an investment calculation versus following a heuristic approach. If one is also interested in the different types of heuristic based approaches, then the choice of decision strategy could be modeled in a multinomial logit framework. Note that this may be simple to estimate in a single equation setting, but otherwise, a simultaneous determination of a multinomial outcome variable and a binary outcome variable would be much more complex.

appropriate treatment of a model where two binary variables are simultaneously determined. The computation of marginal effects in such a setting were also discussed in details in Greene (1998). In the literature it is possible to find several studies that use a recursive bivariate probit model.[8]

The outcome variables (correct choice of appliance, choice of decision-making strategy) are both dichotomous and are jointly modeled allowing for a correlation between the error terms of the two equations. The decision strategy outcome variable is endogenous and also appears as an explanatory variable in the equation for the appliance choice (hence the term 'recursive'). Hence, our recursive bivariate setting looks like:

$$y_1^* = \boldsymbol{\beta}_1'\mathbf{x}_1 + \varepsilon_1,\ y_1 = 1 \text{ if } y_1^* > 0, y_1 = 0 \text{ otherwise,} \tag{9}$$

$$y_2^* = \boldsymbol{\beta}_2'\mathbf{x}_2 + \delta y_1 + \varepsilon_2,\ y_2 = 1 \text{ if } y_2^* > 0, y_2 = 0 \text{ otherwise} \tag{10}$$

where it holds that

$$[\varepsilon_1, \varepsilon_2] \sim \Phi_2[0, 0, 1, 1, \rho], \rho \in [-1, 1]$$

Φ_2 indicates the distribution function for the bi-variate standard normal distribution with ρ as the dependency parameter. δ is the coefficient on the binary investment analysis outcome variable from the first step appearing in the appliance choice equation in the second step.

The variables in our model are:

$$y_1 = \text{Decision to perform an investment analysis } (= INVCALC)$$

$$y_2 = \text{Correct choice of appliance } (= CHOIC)$$

$$\mathbf{x}_1 = \text{Independent variables in the investment analysis equation}$$

$$\mathbf{x}_2 = \text{Independent variables in the appliance choice equation}$$

The exogenous variables in the model consists of: socioeconomic characteristics of the respondent (age, sex and if he/she has an university education) and that of the household (household income and if the residence is owned or rented); environment related attitudes; the level of energy and financial literacy of the respondent; the treatment variable (i.e. yearly electricity consumption shown

[8]See for instance, Jones (2007) who analyzes individual's self-assessed health and smoking and Kassouf and Hoffmann (2006) who analyze the probability of suffering work-related injuries and use of personal protective equipment. Some of the recent studies in energy related application areas are: Martínez-Espiñeira and Lyssenko (2011), Shi (2014), Pérez-Urdiales and García-Valiñas (2016).

in physical or monetary units) and some other variables like language in which the survey was taken and the order in which the two appliance choices were presented.

It is important to note that the model is identified irrespective of whether the exogenous variables $\mathbf{x}_1$ and $\mathbf{x}_2$ in the two equations are different or not.[9] Moreover, such a recursive model of simultaneous equation can be estimated using the full information maximum likelihood (FIML) approach ignoring the simultaneity.[10]

For the model specified in equations (9) and (10), following Greene (1998), probability of the two outcomes may be written as:

$$\begin{aligned} Pr[y_2 = 1, y_1 = 1|\mathbf{x}_1, \mathbf{x}_2] &= \Phi_2(\boldsymbol{\beta}_1'\mathbf{x}_1, \boldsymbol{\beta}_2'\mathbf{x}_2 + \delta, \rho) \\ Pr[y_2 = 1, y_1 = 0|\mathbf{x}_1, \mathbf{x}_2] &= \Phi_2(-\boldsymbol{\beta}_1'\mathbf{x}_1, \boldsymbol{\beta}_2'\mathbf{x}_2, -\rho) \\ Pr[y_2 = 0, y_1 = 1|\mathbf{x}_1, \mathbf{x}_2] &= \Phi_2(\boldsymbol{\beta}_1'\mathbf{x}_1, -\boldsymbol{\beta}_2'\mathbf{x}_2 - \delta, -\rho) \\ Pr[y_2 = 0, y_1 = 0|\mathbf{x}_1, \mathbf{x}_2] &= \Phi_2(-\boldsymbol{\beta}_1'\mathbf{x}_1, -\boldsymbol{\beta}_2'\mathbf{x}_2, \rho) \end{aligned} \tag{11}$$

Given the probabilities in (11), the conditional mean for the correct appliance choice could then be written as

$$\begin{aligned} \mathrm{E}[y_2|y_1 = 1, \mathbf{x}_1, \mathbf{x}_2] &= \frac{Pr[y_2 = 1, y_1 = 1|\mathbf{x}_1, \mathbf{x}_2]}{Pr[y_1 = 1|\mathbf{x}_1, \mathbf{x}_2]} \\ &= \frac{\Phi_2(\boldsymbol{\beta}_1'\mathbf{x}_1, \boldsymbol{\beta}_2'\mathbf{x}_2 + \delta, \rho)}{\Phi(\boldsymbol{\beta}_1'\mathbf{x}_1)} \end{aligned} \tag{12}$$

Moreover, the unconditional mean function can then be written as

$$\begin{aligned} \mathrm{E}[y_2|\mathbf{x}_1, \mathbf{x}_2] &= Pr[y_1 = 1|\mathbf{x}_1, \mathbf{x}_2] \cdot \mathrm{E}[y_2|y_1 = 1, \mathbf{x}_1, \mathbf{x}_2] \\ &\qquad + Pr[y_1 = 0|\mathbf{x}_1, \mathbf{x}_2] \cdot \mathrm{E}[y_2|y_1 = 0, \mathbf{x}_1, \mathbf{x}_2] \\ &= Pr[y_2 = 1, y_1 = 1|\mathbf{x}_1, \mathbf{x}_2] + Pr[y_2 = 1, y_1 = 0|\mathbf{x}_1, \mathbf{x}_2] \\ &= \Phi_2(\boldsymbol{\beta}_1'\mathbf{x}_1, \boldsymbol{\beta}_2'\mathbf{x}_2 + \delta, \rho) + \Phi_2(-\boldsymbol{\beta}_1'\mathbf{x}_1, \boldsymbol{\beta}_2'\mathbf{x}_2, -\rho) \end{aligned} \tag{13}$$

In a non-linear model, marginal effects are more informative than coefficients, because they inform us how the outcome variable will change when an explanatory variable changes. The marginal effects

[9] See Wilde (2000) and Greene (2003).

[10] See Maddala (1983, p. 123) for a proof and Greene (2003) for few extensions.

can be calculated for each observation i or for any specific vector of the regressors. In this study, the marginal effects are calculated for the sample mean.

The expression for the marginal effects[11] could be derived following Greene (1998) and Kassouf and Hoffmann (2006). For a two equation model, one would obtain a *direct* effect for variables appearing on the right hand-side of the choice equation (i.e. $\mathbf{x}_2$) and an *indirect* effect for explanatory variables in the decision strategy equation (i.e. $\mathbf{x}_1$). The indirect effect on the correct choice occurs via the endogenous decision strategy variable which also appears on the right-hand side of the choice equation. The total effect is then the sum of the direct and the indirect effects.

There are different variable types to be considered, namely, the endogenous binary outcome y_1, binary explanatory variables in either (or both) equations, and continuous explanatory variables in either (or both) equations. The influence of using investment analysis as the decision strategy on the choice of the cost-efficient appliance can be calculated as its effect on the probability of the marginal distribution which is given by

$$M(y_1) = \Phi(\boldsymbol{\beta}_2'\mathbf{x}_2 + \delta) - \Phi(\boldsymbol{\beta}_2'\mathbf{x}_2) \tag{14}$$

The effect of an exogenous binary variable (say q) is calculated by comparing the effect on the outcome when this binary variable assumes a value 1 compared to when it has a value 0. The other variables are kept at their mean values. Let $\mathbf{q}_1$ represent the set of vectors $\mathbf{x}_1$ and $\mathbf{x}_2$ when $q = 1$ and other variables are at their means. Similarly, let $\mathbf{q}_0$ represent the set of the exogenous vectors in both equations when $q = 0$ and other variables are at their means values.

The total marginal effect of q could be thought as the sum of two parts, effect on those who have an optimization decision strategy in the first step ($y_1 = 1$) and an effect on those without an optimization decision strategy ($y_1 = 0$). This is equivalent to writing:

$$\begin{aligned} M(q) = {} & (Pr[y_2 = 1, y_1 = 1|\mathbf{q}_1] - Pr[y_2 = 1, y_1 = 1|\mathbf{q}_0]) \\ & + (Pr[y_2 = 1, y_1 = 0|\mathbf{q}_1] - Pr[y_2 = 1, y_1 = 0|\mathbf{q}_0]) \end{aligned} \tag{15}$$

Similarly, the effect of an exogenous continuous variable (say z) is calculated by computing the partial

[11] As noted in Greene (2003) and Christofides et al. (1997), in a two-equation setting it is not always absolutely clear on what margins are the effects being calculated by the empirical analyst and/or estimation software. There exist more than one option in terms of choosing the margins at which effects could be calculated. Naturally, the choice of the margin might also depend upon the use case.

derivative of the unconditional mean function in equation (13) with respect to z. The somewhat complicated expression appears in Kassouf and Hoffmann (2006, p.115) and the analysis appears more generally in Greene (1996, 1998).

We are interested in calculating the impact of at least four variables of interest on the choice of decision strategy and in turn on the correct choice of the (cost-)efficient appliance — energy literacy, investment literacy, monetary treatment and the endogenous decision strategy to make an investment analysis. We have used NLOGIT for the model estimation and calculation of the marginal effects presented in this paper.[12]

5 Results

Below we present the estimation results for our two choice experiments. Three probit models were estimated for each of the two experiments for comparison purpose — the single equation probit (*Probit*), bivariate probit (*Biv. Probit*) and the recursive bivariate probit (*Rec. Biv. Probit*). These models give us insights into the factors that influence the decision strategy and the choice of the appliance that minimizes total cost over the entire lifetime. Table 2 presents the empirical results from *Experiment 1*, the light-bulb choice experiment. Following this, Table 3 shows the results from *Experiment 2*, the fridge choice experiment. Finally we compare the results across the two experiments and present the estimated marginal effects for our quantities of interest, i.e. energy literacy, investment literacy, monetary treatment and investment analysis strategy on the choice of appliances.

As explanatory variables, we include age of the respondent (in three age groups[13]), gender (being female), education (holding an academic degree) as well as monthly gross household income (in three income groups).[14] The ownership status of the residence (owned or rented) is also controlled

[12] A note on the software used for analysis: we noticed that the recursive bivariate model itself can be easily estimated by several econometric software programs (e.g., NLOGIT, STATA and R). However, the calculation of the marginal effects is not at all straightforward. Of the three mentioned programs, we found that the inbuilt PARTIAL EFFECTS routine within NLOGIT was the only helpful and consistent tool that appears to correctly handle the computation of the marginal effects for different types of variables within the recursive bivariate model.

[13] Less than 40 years (reference category), 40 – 60 years and 60 years or above.

[14] The three income groups are: less than CHF 6'000 ($HHI6K$ as reference category); between CHF 6'000 – CHF 12'000 ($HHI6\_12K$); and more than CHF 12'000 ($HHI12K$). Missing values on the household income variable either due to non-response or selecting "Don't know/No Answer" as a response were imputed using standard multiple imputation approach. We make use of available socioeconomic information like employment status of respondent and his/her partner, their education level, number of people within the house, age and sex of the respondent etc. and available residence characteristics like living in an owned or rented residence, if it is a single family house or an apartment, size of the residence, postcode etc.

for as is the survey language in which the respondent took the survey.[15] Apart from these socio-demographic variables, we control for the respondents' level of energy literacy ($ENLIT\_IN$) and investment literacy ($INVLIT$) as has already been described earlier. Furthermore, we account for the individual's pro-environmental moral attitude ($ATTMORAL$) and their concern for free-riding ($ATTCONCE$). Finally, we control for the treatment effects of displaying the yearly electricity consumption in monetary terms ($TREATCHF$), as well as for any effect of the order in which the two appliance choices are presented ($ORDEFF$).

EMPIRICAL RESULTS

The results of the three probit regressions for the lightbulb choice experiment are presented in Table 2. For the investment calculation equation, the slope coefficients are quite similar across the three models. Differences are apparent in the appliance choice equation, particularly when comparing the first two models to the recursive bivariate probit. The investment calculation strategy is significant with a positive sign in the recursive biprobit and the monetary treatment is no longer significant. Interestingly socioeconomic characteristics and energy and investment literacy only impact the choice of the appliance indirectly via the choice of investment calculation as the decision strategy. Note that estimate of the dependency parameter ρ is small and insignificant in the normal bivariate probit, which explains the similar estimates in *Probit* and *Biv. Probit* models.

Table 3 presents the result for *Experiment 2* for refrigerator choices. Here too, most of the differences are again seen in the appliance choice equation. Note that ρ now is significant for bivariate probit model and the estimated are different when compared to single equation probit. In the recursive bivariate probit, the effects of endogenous decision strategy variable is stronger, however, that of energy and investment literacy is smaller compared to the other two models. Higher income levels are seen to be positively associated with the correct choice of appliance in the first two probit models.

From the presented estimation results of both experiments, we observe a negative effect of a higher age (i.e. respondent older than 60 years compared to adults who are less than 40 years old) on the decision strategy to choose an investment analysis approach. However this slope coefficient is usually insignificant in the appliance choice step (in *Experiment 1*, it even has a positive and

[15] A dummy variable for Italian in experiment 1 ($ITALSP$) and a dummy variable for French in experiment 2 ($FRENCHSP$).

Table 2: Results of Experiment 1 (robust standard errors in parentheses).

	Experiment 1: Light Bulb Choice ($N = 1,958$)		
Model	*Probit*	*Biv. Probit*	*Rec. Biv. Probit*
	Investment Calculation Equation ...		
Constant	-1.4462***	-1.4455***	-1.4301***
	(0.1404)	*(0.1399)*	*(0.1400)*
FEMALE	-0.2893***	-0.2907***	-0.2992***
	(0.0757)	*(0.0774)*	*(0.0771)*
AGE40_59	-0.0241	-0.0251	-0.0365
	(0.0862)	*(0.0873)*	*(0.0874)*
AGE60P	-0.3046***	-0.3060***	-0.3202***
	(0.0931)	*(0.0935)*	*(0.0936)*
OWNER	0.1414*	0.1413*	0.1394*
	(0.0727)	*(0.0744)*	*(0.0744)*
HHI6_12K	0.0706	0.0705	0.0743
	(0.0814)	*(0.0827)*	*(0.0825)*
HHI12K	0.1579	0.1582	0.1689
	(0.1087)	*(0.1110)*	*(0.1109)*
UNIEDU	0.1937***	0.1930***	0.1767**
	(0.0711)	*(0.0714)*	*(0.0699)*
ATTMORAL	-0.0548	-0.0549	-0.0525
	(0.0794)	*(0.0802)*	*(0.0801)*
ENLIT_IN	0.0451***	0.0448***	0.0439***
	(0.0120)	*(0.0123)*	*(0.0123)*
INVLIT	0.4938***	0.4972***	0.4979***
	(0.0792)	*(0.0787)*	*(0.0782)*
TREATCHF	0.3510***	0.3518***	0.3547***
	(0.0662)	*(0.0667)*	*(0.0666)*
	Appliance Choice Equation ...		
Constant	1.1966***	1.1837***	0.9775***
	(0.1958)	*(0.2045)*	*(0.2079)*
FEMALE	0.0843	0.0934	0.1898
	(0.1115)	*(0.1216)*	*(0.1157)*
AGE40_59	0.0600	0.0611	0.0705
	(0.1253)	*(0.1276)*	*(0.1178)*
AGE60P	0.1939	0.2020	0.2951**
	(0.1398)	*(0.1449)*	*(0.1362)*
OWNER	0.0866	0.0842	0.0311
	(0.1182)	*(0.1211)*	*(0.1122)*
HHI6_12K	0.0640	0.0595	0.0046
	(0.1176)	*(0.1293)*	*(0.1227)*
HHI12K	-0.0451	-0.0540	-0.1461
	(0.1570)	*(0.1659)*	*(0.1585)*
ITALSP	0.0242	0.0256	0.0619
	(0.1211)	*(0.1295)*	*(0.1170)*
ATTMORAL	0.1582	0.1584	0.1466
	(0.1162)	*(0.1271)*	*(0.1201)*
ATTCONCE	0.2238	0.2232	0.2243
	(0.2151)	*(0.2410)*	*(0.2208)*
ORDEFF	-0.1527	-0.1505	-0.1334
	(0.1005)	*(0.1107)*	*(0.1013)*
ENLIT_IN	0.0316*	0.0300*	0.0063
	(0.0187)	*(0.0181)*	*(0.0223)*
TREATCHF	0.2815***	0.2716**	0.1317
	(0.1017)	*(0.1108)*	*(0.1266)*
INVCALC	-0.0872	—	0.8725**
	(0.1212)	—	*(0.3586)*
RHO(1,2)	—	-0.0753	-0.5961***
	—	*(0.0772)*	*(0.2071)*

***, **, * $\Rightarrow$ Significance at 1%, 5%, 10% level.

Table 3: Results of Experiment 2 (robust standard errors in parentheses).

	Experiment 2: Refrigerator Choice ($N = 877$)		
Model	*Probit*	*Biv. Probit*	*Rec. Biv. Probit*
	Investment Calculation Equation ...		
Constant	-1.5717***	-1.4353***	-1.5687***
	(0.2153)	*(0.2069)*	*(0.2179)*
FEMALE	-0.4838***	-0.4891***	-0.4692***
	(0.1222)	*(0.1259)*	*(0.1276)*
AGE40_59	-0.1949	-0.1845	-0.1996
	(0.1526)	*(0.1629)*	*(0.1577)*
AGE60P	-0.4837***	-0.4395***	-0.5539***
	(0.1634)	*(0.1628)*	*(0.1628)*
OWNER	0.0027	-0.0166	0.0609
	(0.1288)	*(0.1313)*	*(0.1343)*
HHI6_12K	0.1324	0.1814	0.0844
	(0.1286)	*(0.1290)*	*(0.1316)*
HHI12K	0.0676	0.1641	-0.0147
	(0.1816)	*(0.1817)*	*(0.1898)*
UNIEDU	0.2107*	0.0719	0.2739**
	(0.1181)	*(0.1100)*	*(0.1114)*
ATTMORAL	-0.0792	-0.0579	-0.0681
	(0.1198)	*(0.1231)*	*(0.1246)*
ENLIT_IN	0.0435**	0.0444**	0.0437**
	(0.0198)	*(0.0205)*	*(0.0203)*
INVLIT	0.6483***	0.4632***	0.6643***
	(0.1357)	*(0.1317)*	*(0.1361)*
TREATCHF	0.5730***	0.5661***	0.5467***
	(0.1107)	*(0.1144)*	*(0.1138)*
	Appliance Choice Equation ...		
Constant	-1.6114***	-1.2912***	-1.6517***
	(0.2313)	*(0.2043)*	*(0.2157)*
FEMALE	-0.1941	-0.3845***	-0.0185
	(0.1240)	*(0.1208)*	*(0.1256)*
AGE40_59	-0.2425	-0.2736*	-0.1704
	(0.1619)	*(0.1541)*	*(0.1692)*
AGE60P	-0.1291	-0.3057*	0.0012
	(0.1659)	*(0.1570)*	*(0.1642)*
OWNER	-0.0104	-0.0009	0.0057
	(0.1309)	*(0.1258)*	*(0.1195)*
HHI6_12K	0.3297**	0.3849***	0.2004
	(0.1306)	*(0.1254)*	*(0.1287)*
HHI12K	0.4706***	0.5089***	0.3161*
	(0.1750)	*(0.1688)*	*(0.1635)*
FRENCHSP	0.0020	-0.0070	-0.0024
	(0.1202)	*(0.1054)*	*(0.1098)*
ATTMORAL	-0.2154*	-0.2002*	-0.1539
	(0.1212)	*(0.1154)*	*(0.1150)*
ATTCONCE	0.1825	0.1577	0.2165
	(0.2138)	*(0.1985)*	*(0.1903)*
ORDEFF	-0.0987	-0.0830	-0.0715
	(0.1119)	*(0.0994)*	*(0.1024)*
ENLIT_IN	0.0698***	0.0808***	0.0457**
	(0.0205)	*(0.0189)*	*(0.0200)*
TREATCHF	0.5299***	0.6885***	0.2971***
	(0.1144)	*(0.1074)*	*(0.1151)*
INVCALC	1.3794***	—	2.5436***
	(0.1284)	—	*(0.1657)*
RHO(1,2)	—	0.6633***	-0.8162***
	—	*(0.0524)*	*(0.1184)*

***, **, * $\Rightarrow$ Significance at 1%, 5%, 10% level.

significant value). Furthermore, there seems to be a significant negative effect of gender on choosing an investment analysis approach, and in turn on the choice of the appliance. A positive effect of university education ($UNIEDU$) is observed in both the experiments.

As discussed before, the energy and investment literacy of respondents is captured in two variables: the energy literacy index ($ENLIT\_IN$) and the ability to do a compound interest calculation ($INVLIT$). We observe a positive and significant effect of energy and investment literacy, which is robust across all specifications. This supports *Hypothesis H1a* in that individuals with a higher cognitive ability are more likely to follow an optimization strategy rather than a heuristic strategy. There is also a significant positive effect of choosing an optimization decision strategy, which in turn supports *Hypothesis H2a*. All these effects are in particular found to be stronger in *Experiment 2*, in which making an investment calculation was the only way to identify the more efficient appliance. A negative and weakly significant effect of pro-environmental attitudes can be observed for *Experiment 2* in the (bivariate) probit models, which could be due to the fact that a choice based on just a pro-environmental moral attitude, i.e. considering mainly the efficiency rating or the electricity consumption in kWh, would lead to an incorrect choice given the two refrigerators.

The effect of being in the treatment with monetary information on yearly electricity consumption is strong and highly significant in almost all model specifications thereby supporting *Hypotheses H1b and H2b*. As expected, the treatment effects are stronger in the fridge choice experiment. No significant order effect are found in either experiment which indicates absence of any bias due to the order of the presented appliance choices.

The correlation coefficient between the two error terms, ρ, is found to be significant in both experiments and supports the (recursive) bivariate specification. In experiment 2, the estimated ρ is noticed however to change signs and become negative when comparing the *Rec. Biv. Probit* to the *Biv. Probit* setting. A possible explanation could be that not everyone who claimed to have performed an investment analysis actually did so (or at least performed it correctly)! From the fridge experiment sample, we do notice about 37% of respondents claiming to have performed an investment analysis as their decision strategy but still incorrectly selecting the more costly fridge as the most (cost-)efficient appliance.

MARGINAL EFFECTS

In Table 4, we present the marginal effects at the sample means for the variables that are particularly important to verify our hypotheses. The marginal effects are computed for two variables measuring energy and investment literacy, the dummy variable capturing the treatment effect of displaying yearly energy consumption in monetary terms, as well as the endogenous dummy variable of choosing an investment analysis decision strategy. We restrict the discussion on the reported results for our preferred model which is the recursive bivariate probit.

It is shown that the fact that an individual is able to do complex calculations increases the probability to choose the most cost-efficient appliance by 2–3 percentage points in *Experiment 1* and by about 19–20 percentage points in *Experiment 2*. Similarly, an increase in an individual's energy literacy score (measured on a scale of 0 to 14) also increases the probability to choose the most cost-efficient appliance. The higher marginal effect in *Experiment 2* (3 percentage points) can most likely be attributed to the fact that in this experiment, the most cost-efficient appliance could only be identified when comparing lifetime usage costs of both appliances, which requires some calculation. In *Experiment 1*, also the comparison of the power of the two light bulbs, their lifetime or the comparison of the energy-efficiency rating on the label lead to the choice of the most cost-efficient appliance. Hence, the cognitive abilities of the respondents in terms of their ability to make complex calculations were less important here.

Table 4: Marginal effects (at means).

	Experiment 1: Light Bulb Choice			**Experiment 2: Refrigerator Choice**		
Model	*Probit*[1]	*Biv. Probit*[2]	*Rec. Biv. Probit*[2]	*Probit*[1]	*Biv. Probit*[2]	*Rec. Biv. Probit*[2]
INVLIT	—	0.1289	0.0293	—	0.2148	0.1965
ENLIT_IN	0.0030	0.0124	0.0032	0.0142	0.0009	0.0313
TREATCHF	0.0267	0.0976	0.0360	0.1107	0.0935	0.2934
INVCALC[3]	-0.0087	—	0.0777	0.4153	—	0.7786

[1] Effects shown here are just for the appliance choice equation.
[2] Marginal effects of exogenous dummy variables are on those with $INVCALC = 1$, i.e. the first part of the total effect in Equation (15).
[3] For endogenous $INVCALC$ in the recursive biprobit, marginal effects are calculated using Equation (14).

For the same reason, also the marginal effects of providing the yearly energy consumption in monetary terms rather than physical units are much higher for *Experiment 2*. While the probability to choose the most cost-efficient light bulb increased by about 4 percentage points when the monetary information was displayed in *Experiment 1*, the probability increased by about 30 percentage points in the case of the refrigerator choice (*Experiment 2*).

The effect of the monetary information treatment seems very robust across different specifications, which gives strong support for *Hypotheses H1b and H2b*, i.e. that the information on yearly energy costs strongly increases the chances that consumers choose the more (cost-)efficient appliance.

Lastly, marginal effect of the endogenous investment calculation decision strategy variable is up to 8 percentage points in *Experiment 1* and up to 78 percentage points in *Experiment 2*. The strong impact supports our *Hypothesis H2a* that opting for optimization as the decision-making strategy has a positive impact on the probability to identify the most cost-efficient appliance.

6 Conclusion

In order to examine the role of information display, energy and investment literacy on the choice of electrical appliances of consumers, we have organized a household survey and conducted two online randomized control experiments among Swiss households from three major Swiss urban areas. The first experiment was related to a choice among two light bulbs whereas the second experiment was concerned with making a choice among two refrigerators. The information collected from the survey was analyzed by estimating a series of (recursive) bivariate probit models in order to simultaneously model two binary variables which represent the two stage decision process explaining first the adoption of a decision strategy based on investment calculation and then the choice of the cost efficient appliance.

From the survey we observe that more than two-third of the consumers do not perform an investment calculation, which supports the view that a large part of the consumers are boundedly rational. Further, from the econometric analysis we observe that displaying yearly energy consumption of appliances in estimated yearly energy cost rather than in physical units increases both the probability that consumers perform an investment analysis and that they identify the most (cost-)efficient appliances. Therefore, our results emphasize that informed and rational choices of appliances can be enhanced by the provision of monetary information on yearly energy consumption. Furthermore, we could show that individuals who possess energy-related knowledge and high cognitive abilities, captured by high levels of energy and investment literacy, were more likely to opt for optimization as the decision-making strategy which in turn positively influences the probability to identify the most cost-efficient appliance. It can therefore be concluded, that enhancing an individual's energy-related knowledge and the ability to make complex (investment) calculations seems to be one important prerequisite to empower consumers to make rational and informed energy-related choices.

From an energy policy point of view, the results suggest that an improvement in energy efficiency could be reached in two ways. First, with an obligation for the producers of electrical appliances to provide information on the future energy consumption of the product in the form of a monetary estimate. Second, by promoting educational training and providing decision support tools at the point of sale to increase the level of energy-related investment literacy of the consumers.

References

Allcott, H. and Greenstone, M.: 2012, Is There an Energy Efficiency Gap?, *Journal of Economic Perspectives* **26**(1), 3–28.

Allcott, H. and Taubinsky, D.: 2015, Evaluating Behaviorally Motivated Policy: Experiment Evidence from the Lightbulb Market, *American Economic Review* **105**(8), 2501–2538.

Anderson, C. and Claxton, J.: 1982, Barriers to Consumer Choice of Energy Efficient Products, *Journal of Consumer Research* **9**, 163–170.

BFE: 2015, Schweizerische Gesamtenergiestatistik 2014, *Technical report*, Bundesamt für Energie - BFE.

Broberg, T. and Kazukauskas, A.: 2015, Inefficiencies in Residential Use of Energy - A Critical Overview of Literature and Energy Efficiency Policies in the EU, *International Review of Environmental and Resource Economics* **8**(2), 225–279.

Brounen, D., Kok, H. and Quigley, J.: 2013, Energy literacy, awareness, and conservation behavior of residential households, *Energy Economics* **38**, 42–50.

Brown, M. and Graf, R.: 2013, Financial Literacy and Retirement Planning in Switzerland, *Numeracy* **6**(2), Article 6.

Bruderer Enzler, H., Diekmann, A. and Meyer, R.: 2014, Subjective discount rates in the general population and their predictive power for energy saving behavior, *Energy Policy* **65**, 524 – 540.

Burnett, N. J.: 1997, Gender Economics Courses in Liberal Arts Colleges, *The Journal of Economic Education* **28**(4), 369–376.

Christofides, L. N., Stengos, T. and Swidinsky, R.: 1997, On the calculation of marginal effects in the bivariate probit model, *Economics Letters* **54**(3), 203–208.

Coller, M. and Williams, M. B.: 1999, Eliciting Individual Discount Rates, *Experimental Economics* **2**(2), 107–127.

Conlisk, J.: 1988, Optimization cost, *Journal of Economic Behavior & Organization* **9**(3), 213 – 228.

Deaton, A. and Muellbauer, J.: 1980, *Economics and consumer behavior*, Cambridge University Press, Cambridge.

Deutsch, M.: 2010, The effect of life-cycle cost disclosure on consumer behavior: evidence from a field experiment with cooling appliances, *Energy Efficiency* **3**, 303–315.

DeWaters, J. and Powers, S.: 2011, Energy literacy of secondary students in New York State (USA): A measure of knowledge, affect, and behavior, *Energy Policy* **39**, 1699–1710.

Epper, T., Fehr-Duda, H. and Schubert, R.: 2011, Energy-Using Durables: The Role of Time Discounting in Investment Decisions, Swiss Federal Office of Energy, Publication No. 290417.

Flaig, G.: 1990, Household production and the short-and long-run demand for electricity, *Energy Economics* **12**(2), 116–121.

Frederiks, E., Stenner, K. and Hobman, E.: 2015, Household energy use: Applying behavioural economics to understand consumer decision-making and behaviour, *Renewable and Sustainable Energy Reviews* **41**, 1385–1394.

Greene, W. H.: 1996, Marginal Effects in the Bivariate Probit Model, *text*, New York University, Leonard N. Stern School of Business, Department of Economics.

Greene, W. H.: 1998, Gender Economics Courses in Liberal Arts Colleges: Further Results, *The Journal of Economic Education* **29**(4), 291–300.

Greene, W. H.: 2003, *Econometric analysis*, 5th edn, Prentice Hall, Upper Saddle River, N.J.

Harrison, G. W., Lau, M. I. and Williams, M. B.: 2002, Estimating Individual Discount Rates in Denmark: A Field Experiment, *American Economic Review* **92**(5), 1606–1617.

Hausman, J. A.: 1979, Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables, *The Bell Journal of Economics* **10**(1), 33–54.

Heinzle, S. L.: 2012, Disclosure of Energy Operating Cost Information: A Silver Bullet for Overcoming the Energy-Efficiency Gap?, *Journal of Consumer Policy* **35**(1), 43–64.

Hille, S., Geiger, C. and Loock, M.: 2015, Camouflaging environmental impact through relative rating: the case of eco-labels for cars, *Conference Proceedings of the 2nd SCCER CREST Conference 2015 - On the implementation of the energy transition: The impact of Economic, Environmental and Political Action*, pp. 69–74.

Hlavac, M.: 2015, *stargazer: Well-Formatted Regression and Summary Statistics Tables*, Harvard University, Cambridge, USA. R package version 5.2.

Howarth, R. B. and Sanstad, A. H.: 1995, Discount Rates and Energy Efficiency, *Contemporary Economic Policy* **13**, 101–109.

Jones, A. M.: 2007, *Applied econometrics for health economists: a practical guide*, 2. ed edn, Radcliffe, Oxford.

Kassouf, A. L. and Hoffmann, R.: 2006, Work-Related Injuries Involving Children and Adolescents: Application of a Recursive Bivariate Probit Model, *Brazilian Review of Econometrics* **26**(1), 105–126.

Lamport, L.: 1986, *LATEX: A Document Preparation System*, Addison–Wesley Pub. Co., Reading, MA.

Lusardi, A. and Mitchell, O.: 2007, Baby Boomer Retirement Security: The Role of Planning, Financial Literacy, and Housing Wealth, *Journal of Monetary Economics* **54**, 205–224.

Lusardi, A. and Mitchell, O.: 2009, Financial Literacy: Evidence and Implications for Financial Education Programs. Trends and Issues, *Discussion paper*, NBER.

Maddala, G. S.: 1983, *Limited-dependent and qualitative variables in econometrics*, Cambridge University Press, Cambridge [Cambridgeshire]; New York.

Martínez-Espiñeira, R. and Lyssenko, N.: 2011, Correcting for the endogeneity of pro-environment behavioral choices in contingent valuation, *Ecological Economics* **70**(8), 1435–1439.

McNeill, D. and Wilkie, W.: 1979, Public Policy and Consumer Information: Impact of the New Energy Labels, *Journal of Consumer Research* **6**, 1–11.

Mills, B. and Schleich, J.: 2010, What's driving energy efficient appliance label awareness and purchase propensity?, *Energy Policy* **38**, 814–825.

Mills, B. and Schleich, J.: 2012, Residential energy-efficient technology adoption, energy conservation, knowledge, and attitudes: An analysis of European countries, *Energy Policy* **49**, 616–628.

Min, J., Azevedo, I. L., Michalek, J. and de Bruin, W. B.: 2014, Labeling energy cost on light bulbs lowers implicit discount rates, *Ecological Economics* **97**, 42 – 50.

Muth, R. F.: 1966, Household production and consumer demand functions, *Econometrica: Journal of the Econometric Society* **34**(3), 699–708.

Nair, G., Gustavsson, L. and Mahapatra, K.: 2010, Factors influencing energy efficiency investments in existing Swedish residential buildings, *Energy Policy* **38**(6), 2956–2963.

Newell, R. and Siikamäki, J.: 2014, Nudging Energy Efficiency Behavior: The Role of Information Labels, *Journal of the Association of Environmental and Resource Economists* **1**(4), 555–598.

NLOGIT 5: 2012, Econometric Software, Inc., Plainview, New York. www.nlogit.com.

Pérez-Urdiales, M. and García-Valiñas, M. A.: 2016, Efficient water-using technologies and habits: A disaggregated analysis in the water sector, *Ecological Economics* **128**, 117–129.

Pingle, M.: 2015, *Real-world decision making: an encyclopedia of behavioral economics*, Greenwood, chapter Decision Cost, pp. 86–88.

Sallee, J. M.: 2014, Rational Inattention and Energy Efficiency, *The Journal of Law and Economics* **57**(3), 781–820.

Sanstad, A. H. and Howarth, R. B.: 1994a, Consumer Rationality and Energy Efficiency, *Proceedings of the ACEEE 1994 Summer Study on Energy Efficiency in Buildings* pp. 175–183.

Sanstad, A. H. and Howarth, R. B.: 1994b, 'Normal' markets, market imperfections and energy efficiency, *Energy Policy* **22**(10), 811–818.

Shi, L.: 2014, *Econometric analyses of renewable energy promotion*, Diss., Dept. of Forest Economics, Swedish University of Agricultural Sciences.

Simon, H.: 1959, Theories of Decision-Making in Economics and Behavioral Sciences, *The American Economic Review* **49**(3), 253–283.

Train, K.: 1985, Discount rates in consumers' energy-related decisions: A review of the literature, *Energy* **10**(12), 1243 – 1253.

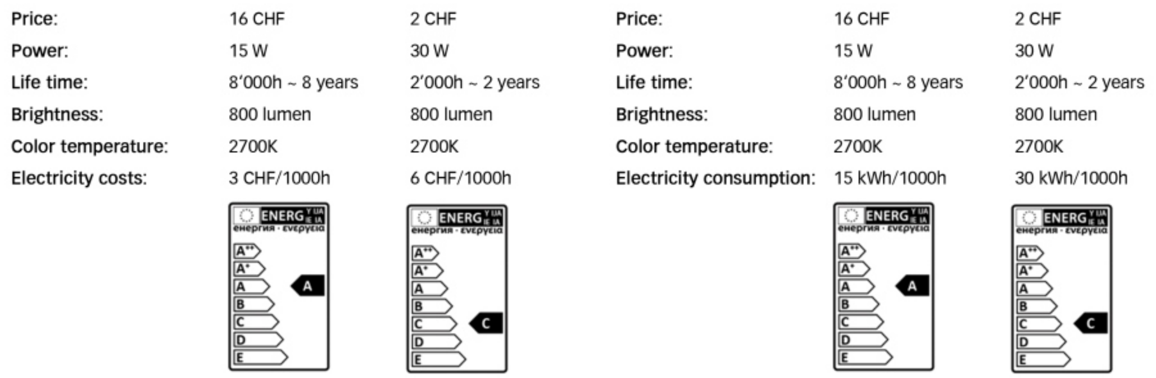
Waechter, S., Sütterlin, B. and Siegrist, M.: 2015, Desired and Undesired Effects of Energy Labels - An Eye-Tracking Study, *PLoS ONE* **10**(7), 1–26.

Wilde, J.: 2000, Identification of multiple equation probit models with endogenous dummy regressors, *Economics Letters* **69**(3), 309–312.

Wilson, C. and Dowlatabadi, H.: 2007, Models of Decision Making and Residential Energy Use, *Annual Review of Environment and Resources* **32**, 169–203.

Appendix

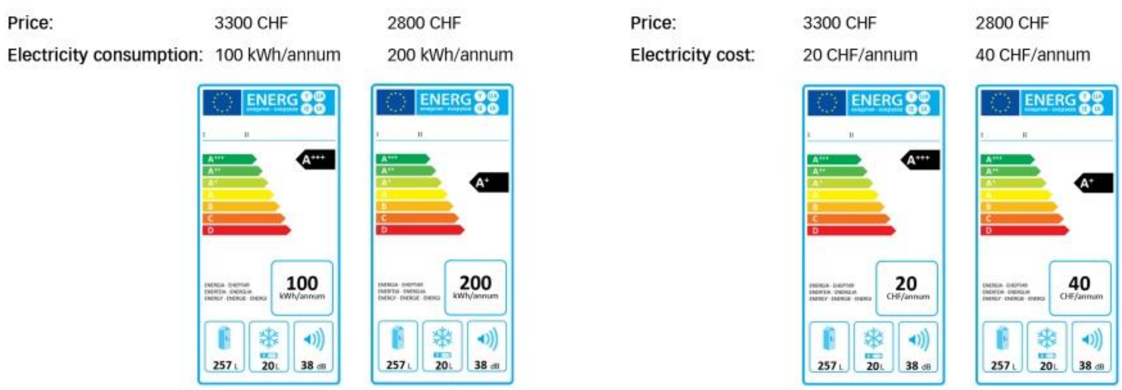
The light bulb choice cards (randomized) with electricity consumption displayed in either physical units (kWh) or monetary units (CHF) are shown in Figure 3. Note that within the set of treatments that are randomly assigned to respondents, there are two more choice cards with the two light bulbs appearing in an opposite order (i.e. with switched positions of the 2 CHF and 16 CHF light bulbs).



(a) Consumption displayed in kWh (b) Consumption displayed in CHF

Figure 3: Light bulb choice card treatments (randomized) as presented in Experiment 1.

The refrigerators choice cards (randomized) with electricity consumption displayed in either physical units (kWh) or monetary units (CHF) are shown in Figure 4. Note that within the set of treatments that are randomly assigned to respondents, there are two more choice cards with the two refrigerators appearing in an opposite order (i.e. with switched positions of the 2'800 CHF and 3'300 CHF refrigerators).



(a) Consumption in kWh (b) Consumption in CHF

Figure 4: Refrigerator choice card treatments (randomized) as presented in Experiment 2.

Table 5: Summary statistics for the light bulb choice experiment.

Statistic	N	Mean	St. Dev.	Min	Max
FEMALE	1,958	0.396	0.489	0	1
AGE40M	1,958	0.270	0.444	0	1
AGE40_59	1,958	0.373	0.484	0	1
AGE60P	1,958	0.358	0.479	0	1
OWNER	1,958	0.420	0.494	0	1
HHI6K	1,958	0.321	0.467	0	1
HHI6_12K	1,958	0.527	0.499	0	1
HHI12K	1,958	0.152	0.359	0	1
UNIEDU	1,958	0.377	0.485	0	1
ENLIT_IN	1,958	4.455	2.853	0	11
INVLIT	1,958	0.668	0.471	0	1
ATTMORAL	1,958	0.782	0.413	0	1
ATTCONCE	1,958	0.075	0.264	0	1
TREATCHF	1,958	0.505	0.500	0	1
ORDEFF	1,958	0.511	0.500	0	1
ITALSP	1,958	0.297	0.457	0	1
INVCALC	1,958	0.229	0.421	0	1
CHOICE	1,958	0.953	0.212	0	1

Table 6: Summary statistics for the fridge choice experiment.

Statistic	N	Mean	St. Dev.	Min	Max
FEMALE	877	0.447	0.497	0	1
AGE40M	877	0.193	0.395	0	1
AGE40_59	877	0.388	0.488	0	1
AGE60P	877	0.420	0.494	0	1
OWNER	877	0.414	0.493	0	1
HHI6K	877	0.403	0.491	0	1
HHI6_12K	877	0.446	0.497	0	1
HHI12K	877	0.152	0.359	0	1
UNIEDU	877	0.363	0.481	0	1
ENLIT_IN	877	3.987	2.748	0	11
INVLIT	877	0.637	0.481	0	1
ATTMORAL	877	0.706	0.456	0	1
ATTCONCE	877	0.070	0.255	0	1
TREATCHF	877	0.491	0.500	0	1
ORDEFF	877	0.481	0.500	0	1
FRENCHSP	877	0.351	0.478	0	1
INVCALC	877	0.176	0.381	0	1
CHOICE	877	0.201	0.401	0	1

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